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AIR FORCE SYSTEMS COMMAND

INTERNATIONAL AVIATION

(Selected Articles)

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TITLE: TEN YEARS OF CHINESE RESEARCH ON AIRCRAFT AEROELASTICS

AUTHOR: Guan De

The years 1979-1989 are the third decade in the development of Chinese research work on aircraft aeroelastics. On the foundation of the previous two decades, and following along with development of and calculations for the various types of aircraft test manufacturing projects in China, the means of experimentation have improved unceasingly. With the diligent efforts of the personnel associated with the broad specialty of aircraft aeroelastics, gratifying progress has been made.

I. CALCULATION OF NON-STEADY STATE AERODYNAMIC FORCES

1. CALCULATION OF SUPERSONIC NON-STEADY STATE AERODYNAMIC FORCES

As far as situations in which chattering of modern military and civilian aircraft is severe is concerned, they often occur in areas of transsonic speeds. In the cases of aircraft which opt for the use

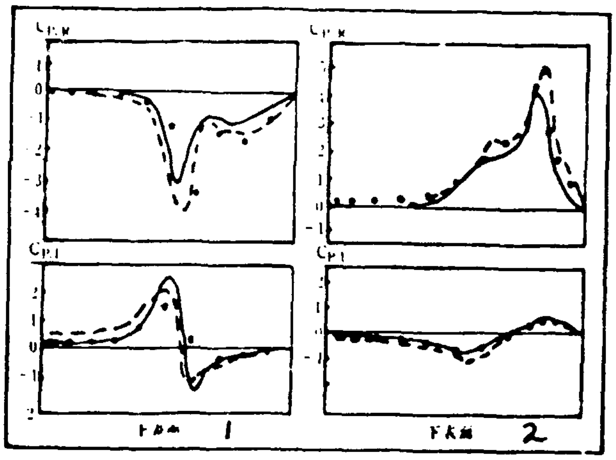

Fig.1 A Comparison of Results from Finite Difference Methods of Calculation and Experiments (C_p is the pressure coefficient. Subscripts R and I, respectively, are the real part and the imaginary part. The angle of attack on the wings of the aircraft is 0^o. The control surface amplitude is 0.5^o.) Key: (1) Upper Surface (2) Lower Surface

of advanced wing forms, transonic speed effects are even more obvious. Aircraft design personnel need to have effective methods for calculating transonic speed, non-steady state aerodynamic forces in order to facilitate the mutual harmonization ot tests from the same wind tunnel. Following along with the unceasing improvements in computer capabilities, for the last ten years, we have developed research work on the two areas below.

The first is the solution by finite difference methods of transonic speed small distrubance equations. At the present time, a calculation program, CTRAN3S, which is capable of being used in many types of planar surface form engineering chatter calculations, has been set up. It is comparable to the XTRAN3S and ATRAN3S which the U.S. currently has. Its accuracy is appropriate, however, its calculation time is greatly shortened. Fig.1 is the calculation results, opting for the use of CTRAN3S, displayed (solid line). The subject of the calculations is the control surface oscillations on the wings of the F-5 aircraft. In the Fig. are given the results of calculations and experiments for chord direction pressure distributions with 50% half wing deployment. It also displays the XTRAN3S calculation results (dotted line), in order to compare materials. It is possible to see that the interval between the calculations and the test results as well as the interval between them and the XTRAN3S calculation results both marry up relatively well.

The second was developing the research work on a set of programing methods to save even more calculation time, for example, integral equation methods brought up outside of China, correction strip methods, equivalent strip methods, and other similar techniques. In conjunction with this, very exciting results were achieved. Use was made of integral equation methods to carry out calculations on pitch oscillations associated with the wings of the F-5 aircraft. Looking from the perspective of a 70% semi-wing deployment and its associated chord pressure distributions, the results from calculations and the results from experimentation basically agree with each other. Use was made of correction strip methods to carry out calculations on swept-back wings with large hypoteneuse ratios of development

and carrying side strips. The equivalent chattering speeds which were calculated out varied with changes in the M number and the test results matched up completely. Use was made of equivalent strip methods to calculate pitch oscillations for swept-back wings with large hypoteneuse ratios of development. The 65% half wing development position's chord direction pressure distributions were basically in line with the results of experiments.

2. CALCULATIONS OF SUB-TRANSONIC NON-STEADY STATE AERODYNAMIC FORCES

In the last ten years, a good deal of work has been done on the area of the calculation of transonic non-steady state aerodynamic forces. The most striking of it has been the independent domestic development of correction piston theory. The amount of calculation work associated with this type of method is very small. However, going through several types of calculations to check, its precision is relatively good. A comparison of calculated and experimental chattering speeds revealed that almost all of them were within $\pm 10\%$ of each other.

In the past, non-steady state aerodynamic force calculations were only capable of handling harmonic or resonant oscillation situations. In order to appropriately respond to the calculation requirements of the course of development during any period of time, improvements were made to the rational approximation methods that were put forward outside of China, raising the efficiency and accuracy of the calculations. At the same time, research was also done on the basis of Green Function methods of calculation.

II. CHATTERING CHARACTERISTICS

1. CHATTERING OF EXTERNALLY SUSPENDED OBJECTS

In the last ten years, with regard to testing composites of objects suspended from the outside of wings with different surfaces for the flexibility of the suspension systems of the hanging objects, large amounts of calculations and experiments were carried out. Not only did these decide concrete questions in the test production of models. Moreover, they obtained a good deal of knowledge with regularities or laws to it.

For example, changes in suspension system parameters for hanging exterior objects carried with them changes in the forms of suspended oscillation by the hanging objects. Through the changes in the forms of the oscillations, it was possible to forsee changes in the forms of chattering. For example, when the pitch frequency of the suspended objects fell, the nodal lines on the surface of the wings, nevertheless, moved forward. Moreover, they gradually changed from a twisting form to a bending form. Following that, the form of the plane's wing chattering also changed from an aircraft wing bending/suspended objects pitched to an aircraft wing bending/twist or torsion form. The chattering speed was greatly increased. Again, in a similar way, as far as suspended fuel tanks with relatively large volumes are concerned, tests were gone through to check out the fuel inertia effects when auxilliary fuel tanks made different forms of movements.

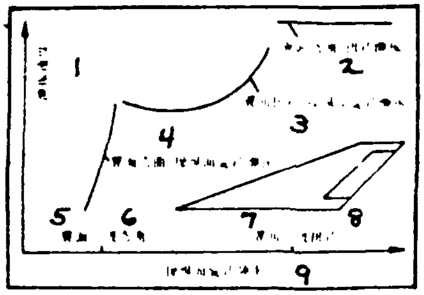

Fig.2 The Mutual Relationships Between Control Surface Rotation Frequencies and the Forms of Chattering. Key: (1) (illegible) Oscillation Speed (2) Wing Surface Bending/(illegible) Twisting Frequency Oscillation (3) Wing Surface Twist (illegible) Control Surface (illegible) Frequency Oscillation (4) Wing Surface Bending/Control Surface Rotation (illegible) Frequency Oscillation (5) Wing Surface (6) (illegible) Bending Surface (7) Wing Surface (8) (illegible) Twisting (illegble) (9) Control Surface Rotation (illegible)

2. CONTROL SURFACE CHATTER

As far as a number of aircraft are concerned, they will encounter the problem of not being able to completely rely on adding and distributing weight in order to eliminate control surface chatter.

Moreover, the form of control surface chatter is also relatively complicated. Going through wind tunnel tests of different combinations of wing surfaces and control surfaces, the mutual relationships between control surface rotation frequencies and the forms of control surface chatter (Fig.2) were explored. It is possible to see that, when control surface rotation frequencies are larger than the wing surface-level twisting frequency, the wing surface bending/control surface rotation chatter disappears. When the control surface rotation frequency is higher than the wing surface-level twisting or torsion frequencies, the wing surface twisting/control surface rotation chatter also disappears. It is turned into bending/rotation chatter, and chatter speeds are clearly increased. With regard to the exploration of these rules or laws, they have very important practical value for aircraft design.

III. AERO-SERVO-ELASTICITY

1. AERO-SERVO-ELASTICITY CALCULATIONS AND TESTS

Methods were set up which made it possible to calculate the aerodymanic servo elasticity characteristics of aircraft which carry driven control systems. In conjunction with this, use was made of aircraft which carry automatic pilot devices or simulation digital electrical control systems. At the same time, the corresponding experimental work was also developed, setting up experimental methods associated with carrier functions for navigating the aircraft as well as resistance characteristics. Results were obtained which could be applied to engineering. As far as aircraft which are equipped with automatic pilot devices or simulation digital type electrically transmitted control systems are concerned, ground tests were completed before the experimental flights, and they proved that test flights would be carried out smoothly.

2. CHATTERING INITIATION RESTRAINTS

During the last ten years, research was developed on numerous types of control patterns or rules. Moreover, these were made use of

with different wing surfaces on models which had the same dynamic characteristics, completing simulation type control system wind tunnel tests. Table 1 is the test results for a delta wing model which carried outboard, externally suspended objects. The control rules or patterns of the tests include those based on laws of aerodynamic energies and those based on modern control theory. The match up between the calculated and experimental results was good.

On this basis, research is just on-going concerning system engineering designs along with research on digital or numerical type systems.

1 控制速度	2 气动能量法	现代控制论 3	
		双目标优4化	极点5配置
6 计 算	42	41	42
7 试 验	40	40.5	40

Table 1 Chatter Initiation Control (1) Control Speed (2) Aerodymanic Energy Laws (3) Modern Control Theory (4) Double Target Optimization (5) Pole Placement

IV. STATIC AERODYNAMIC ELASTICITY

With modern aircraft in low altitude transonic speed ranges, the effects of static aerodynamic elasticity are relatively great. This is particularly true for control surfaces that have cracks in them when they are affected by elasticity deformations associated with control efficiencies with large degrees of deviation or eccentricity, which are difficult to solve for using theoretical methods. Because of this, there were developed methods for making use of rigid model results for measurements of pressures and measurements of forces in order to calculate the characteristics for a flexible model. The results obtained were satisfactory, and the calculations and test results matched up well.

At the same time, calculation methods were also developed involved with aerodymanic force matrices for the aircraft as a whole and based on Green Function methods.

V. STRUCTURAL OPTIMIZATION DESIGNS WHICH CONSIDER CONTROLS ON AEROELASTICS

In the last ten years, two types of wing surface multiple control or restraint optimization design systems have been completed. One type is the YIDOYU system which is based upon penalty function methods, and one type is the SAFDOP system which is based on standard principles of direct observation. Moreover, both of them are universally applicable in engineering design.

In order to adequately bring into play the special characteristics of composite materials in their abnormal rigidity in various directions, development was made of composite material wing surface structural optimization designs which take into consideration aeroelastic control or restraint--research on the aeroelastic tailoring of composite material wing surfaces. Moreover, going through cases of engineering calculations, it was empirically proved that the methods were feasible. Fig.2 is the calculation display for a fighter aircraft wing which opts for the use of a composite material skin and a metallic framework.

VI. SYSTEMS FOR THE ANAYLYSIS OF DYNAMIC FORCES IN AVIATION STRUCTURES

Following along with the development of test manufacturing projects for many types of aircraft, there is a need to rely on a number of commonly used methods to calculate aeroelastics in order to form a universal analysis programming system. Because of this, test manufacture was done of the HAJIF-II system for analyzing dynamic forces in aviation structures. This system is capable of carrying out calculations on aircraft chatter for those carrying driven control systems, static aerodynamic elasticity or aeroelastics, and the effects of sudden winds. These are handled in rigidity matrices. The aerodynamic forces of the component or secondary structures are

combined together along with the programming design arena, and all is created anew.

VII. WIND TUNNEL TESTS

1. SUBCRITICAL RESPONSE MEASUREMENTS

Due to the fact that our country currently possesses high speed wind tunnels with small dimensions, high speeds and pressures, and, according to the requirements for dynamic similarity, model chattering frequencies are al' relatively high, it follows as a result that, when chattering does occur, protection of the model is relatively difficult. In order to facilitate protecting the models, people carried out repeated tests and developed a method for predicting the critical conditions for chattering through measuring subcritical responses. Methods were set up on the basis of random attenuation accumulation and compilation techniques. Moreover, these were used successfully in tests on m ny occasions. The match up between values using subcritical response predictions of critical chattering cc..ditions and the values from experimental measurements is very good.

	优化前 7	优化后 8
颤振速度(米/秒) 1	332	550
重量(千克) 2	420	438
颤振速度导数均匀性 3	-0.08~36.8	1.4~4.0
副翼效率参数 4	0.2	0.23
重量(千克) 5	438	442
副翼效率导数均匀性 6	0.00034~0.019	0.005~0.014

Table 2 Aeroelastic Tailoring of Aircraft Wings with Methods Involving Standard Principles of Direct Observation (1) Chattering Speed (m/sec) (2) Weight (kg) (3) Uniformity of Chattering Speed Derivatives (4) Aileron Efficiency Parameters (5) Weight (kg) (6) Uniformity of Aileron Efficiency Derivatives (7) Before Optimization (8) After Optimization

2. TUNNEL WALL INTERFERENCE

In order to study the influence which wind tunnel walls have on test results during high speed wind tunnel chattering tests, tests were carried out with different model scales and different rates of tunnel wall aperture opening. The results clearly showed that, in situations where the tunnel wall aperture opening rate was a normal one (21.8%), the lowest M numbers for chattering speeds and pressures were not greatly influenced by the scale of the models. When the spread and length of the models occupied 45-70% of the width of the test segment, the lowest chattering speeds and pressures changed to be 7%.

VII. TESTS OF THE INHERENT DYNAMIC CHARACTERISTICS OF STRUCTURES

As far as the main difficulties in testing the inherent dynamic characteristics of structures are concerned, they are that the orthogonality or perpendicularity of the measured forms of the vibrations is not adequate to satisfy requirements and that there is no way to use them in the calculations associated with chattering. In order to resolve this problem, work was principally carried out in two areas.

First of all, improvements were made to the multiple point force adjustment methods. Through cooperation with the Federal Republic of Germany Space Agency, advanced equipment was introduced as well as appropriate test technology. As a result of this, there is a possibility of obtaining inherent vibration forms that meet the requirements for orthogonality or perpendicularity. However, with respect to situations in which inherent frequencies have a high degree of tight concentration, as well as in the interior structure of the aircraft, the multiple point force coordination method still has difficulty meeting the orthogonality or perpendicularity requirements of vibrations forms. Because of this, identification methods for the vibration form parameters of various types of vibration forms were developed, including single point vibratory excitation and multiple point vibratory excitation, time domains and frequency domains, and such classical methods as the multiple input multiple output frequency

domain identification method. These were used in situations which have inherently high degrees of frequency concentration in actual aircraft, and they obtained good results.

IX. FLIGHT CHATTER TESTS

In the decade of the 1970s, a number of flight chatter tests were carried out on aircraft. The striking problems which existed were that the equipment conditions were still very far off the mark. There was also no effective parameter identification method. In the last 10 years, a complete set of relatively advanced equipment has been brought in, making very, very great improvements in real time control and after the fact analysis. At the same time, appropriate parameter recognition techniques were developed.

THE DEVELOPMENT OF THE COMPUTER STUDY OF AERODYNAMICS AND WIND TUNNEL TESTING TECHNOLOGY

Yang Qide

In the last ten years, aerodynamics, following along with the development of aircraft technology, has already achieved enormous results, and it is also facing even more enormous challenges. New ideas and new concepts appear constantly in great numbers. For example, going through changes in the turbulence flow structures inside layers along surfaces to reduce turbulence flow resistance forces, a good deal of experimentation already demonstrates that, making use of non-planar surface walls (grooves, corregated walls, and so on), within low speed ranges, a drop in fuselage drag of 20% is feasible. Aircraft wing laminar flow control has already, by the U.S. and a number of other countries, been introduced into the aerodynamic measures surrounding the next generation of civilian aircraft. Current flight tests clearly show that good design is capable of facilitating the maintaining of laminar flows to Reynolds numbers of $6x10^7$. With the addition of technology to control the initiation of laminar flows, it is possible to have drops in the drag forces for the aircraft as a whole of 25% or more (subsonic speeds). Formed around the foundation of the special characteristics of military aircraft, with their large angles of attack, and applied research, there have been a number of breakthroughs. Close fitted, duck-type side strip aircraft wings and research into the placement of mechanically activated ailerons have already been gradually been put into practical use. As far as the structures and mechanisms of vortices and separations are concerned as well as their calculations, there has already been very great progress. Conforming with the development in craft for spaceflight, high transonic speed flow field analysis, research into shock wave interference, solving for the flow fields of complex exterior forms, as well as the areas of chemistry and thermal environments have also achieved obvious progress. This article will introduce in a general way the trends of development in calculation fluid dynamics (CFD) and wind tunnel test technologies.

CFD, which was developed in the 1970s, is the field of study that has the most lively and most rapid development in modern aerodynamics. In conjunction with this, it has raised powerful challenges to wind tunnel testing. There are people who predict that, by the year 2000,

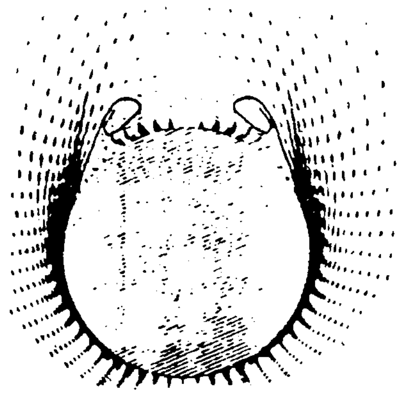

Fig.1 Flow Field for Rotating Body at Large Angle of Attack as Calculated by Such People as Shen Qing and Others

the aircraft design data that is provided by computers will be comparable to that provided by wind tunnels. CFD is capable of being developed further to become a principal design tool. However, wind tunnel testing, by contrast, is a tool for empirical verification and evaluation. For example, during the designing of the F-16, wind tunnel testing used approximately 12,000 hours. However, during the designing of the test verification plane for the forward swept wing, because of the wide spread utilization of CFD, wind tunnel tests were greatly reduced. In the transonic speed range, only 160 wind tunnel hours were used. CFD also caused the lift-drag ratio on the B-70 to go up 30%. The Boeing Company acknowledges that, during the optimization design of transport aircraft wings under cruising conditions, 80% of the work was completed by CFD.

At the present time, computational or calculated aerodynamics is already capable of making use of linear non-viscous equations to

simulate flow fields with small angles of attack, for bodies which have complicated exterior shapes. In conjunction with this, there is a large amount of practical software. Nonviscous, nonlinear equations' Quan Weishi equations and Euler equations are already capable of solving for a good number of aerodynamic characteristics for relatively complicated exterior shapes at transonic speeds. Within China, in this arena, quite a few relatively good programs have been developed. In the calculation of friction drag, pressure distributions, and in the areas of average stress N-S equations as well as other N-S approximation equations, there has been obvious progress in all cases. People such as Chen Zuobin and other similar figures used Euler equations to calculate lines of equal density or lines of equal concentration for complicated exterior forms and other similar cases as well as lines of equal concentration or density for jet flows behind the bodies of jet intake tubes. Shen Qing and other similar people calculated viscous flows for rotating bodies at large angles of attack (Fig.1) and other similar situations.

Outside of China, in the field of calculating viscous flows and flows with large angles of attack, there has also been relatively great development. Fig.2 is the calculation for the interference between viscous high supersonic speed shock waves and shock waves from the blunt entry lips of air intake apertures. In the most recent flow display flight tests of the F/A-18, it was clearly shown that the flight flow spectra around the nose of the aircraft and the diagram of flow movements displayed as the results of calculations matched up quite well.

The techniques involved in CFD include computer grid generation, algorithm research, turbulence modeling, handling before and after calculations, and other similar matters.

THE DEVELOPMENT OF GRID GENERATION TECHNIQUES

This technology is directly related to whether of not calculation methods are able to represent real flow situations or not. Early calculations were done by dividing up grids on planar physical surfaces within an orthogonal coordinate system. Grid points were never on physical boundaries. It was necessary to make use of interpolation values to handle them, and the effects on the precision of calculations were very great. After the 1970s, various types of grid generation techniques appeared. In 1980, at the Lanli (phonetic, possible Langely) Research Center, there was the first instance of the calling of a discussion conference or seminar specializing on the question of grid generation. Up until the present time, grid generation techniques are still an important point in CFD work.

At the present time, the most popular grid is the structural grid. It goes through a number of transformations to become a coordinate plane for the domain of calculation. Solutions are done in a new calculation space. It not only simplifies the handling of boundary conditions, but also raises the precision of calculations on key domain flow fields. Structural grids can be divided into two types. One type is the partial differential equation generation method. On the basis of different problems and solutions, the object or target respectively forms O model, C model, H model, as well as different composite grids. The advantage is that the calculation space is rectangular. However, the equations are relatively complex. The second type is the algebraic generation method. It opts for the

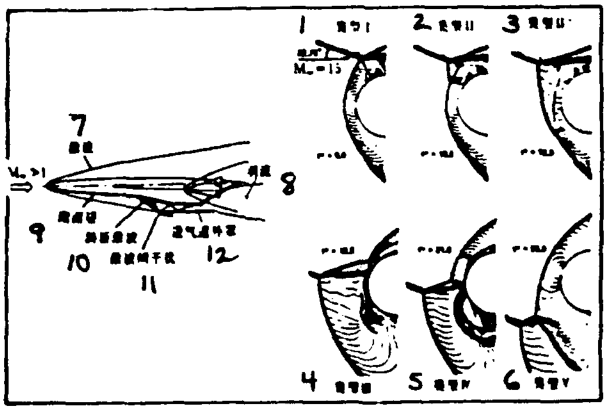

Fig.2 NASA's Calculations of the Interference Between Viscous High Transonic Speed Shock Waves and Shock Waves from the Blunt Lips of Air Intake Entry Ducts. Key: (1) Type I (2) Type II (3) Type II (4) Type III (5) Type IV (6) Type V (7) Shock Wave (8) Plume Flow (9) Layer Along Surface (10) Slanted Plate Shock Wave (11) Interference Between Shock Waves (12) Outside Cover of Air Intake Duct

use of different interpolation methods for forming grids. Expenditures in machine time are small. Their use is flexible. Their shortcoming is that it is very difficult to find appropriate interpolation functions for complicated exterior forms. Another advantage of structural grids is that it is possible to separate methods for gas dynamics solutions and increase flexibility. The disadvantage is that complicated exterior forms must be divided up into pieces, and the handling of the boundary surfaces between pieces is extremely complicated. As a result of this, its uses are limited. Outside of China, this has been reversed, and they have developed a type of non-structural grid method of division into any type of lattice form one wishes. If one is in a two dimensional situation, one resolves it into areas in some arbitrary form of triangular lattice. In a three dimensional situation, by contrast, one uses an arbitrary form of tetrahedral lattice. As a result of this, they improved the suitability for exterior forms. At the present time, the method in question is already capable of being used to solve for the aerodymanic characteristics of whole aircraft similar to the Boeing 747.

Another trend in grid generation is opting for the use of autoadjusting grids, making the formation of lattices capable of changing through the process of resolution, or, in certain designated domains, automatically adding density or concentration. As a result of this, computation times have been reduced, and the accuracy of calculations has been increased. There is also another type of multiple grid technique, which alternates the use of coarse and fine grids. It is possible to effectively eliminate differences between high and low frequencies. They raise the accuracy of calculations, and quicken convergence speeds. There has also been definite development in this area.

ALGORITHM RESEARCH

This type of technology directly influences the accuracy of calculations, stability, and resolution capabilities, as well as the convergence characteristics of solutions. The contents of algorithm research include the separation or divergence of convection flow movement control equations as well as the resolution of separation or divergence equations. Below, only difference calculation methods are taken as examples.

An important problem in difference calculations is making flow field calculations for shock waves. At the present time, on the basis of differences between shock wave calculation methods, it is possible to divide them into shock wave assembly methods and capturing methods. Assembly methods take flow fields in the vicinity of shock waves as well as flow fields that connect smoothly on the outside and separate them for handling. The shock wave and flow field calculations which come from this are all relatively precise and accurate. However, as far as shock waves the locations of which are not known or complicated wave systems are concerned, it has a very difficult time being effective. Capturing methods are capable, in the process of resolution, of automatically capturing shock waves, and it is simple to make use of. However, the shock waves that are calculated are relatively thick.

The earliest difference form which was selected for use was the second order center difference form. During resolution, one usually sees the appearance of a number of high frequency oscillations. Later there were people who added artificial viscosity quantities. Although, they restrained the oscillations associated with solutions in the vicinity of shock waves, the accuracy of the solutions, however, was made lower. Later, second order artificial viscosity methods were also developed. However, the calculated shock waves were still relatively thick. In conjunction with this, they had free parameters. Later, dissipation forms which did not contain free parameters, as well as other mixed forms, and anti-diffusion forms were also developed. The results of the calculations were all improved. However, the shock wave calculations still were not ideal. Straight through to the early 1980s, people developed a number of

total variable difference forms (TVD forms) with reduced values. Calculations did not produce wave movements. There were no free parameters, and they possessed high resolution capabilities. The results were very greatly improved.

The aerodynamic center's Zhang Hanxin discovered that, when making difference divergences in N-S equations and Euler equations, the third degree derivative quantities in corrected equations give rise to important effects in the flow fields in the vicinity of shock waves. If, in the lower reaches of the shock waves, one takes the derivatives in question and selects negative values, selecting positive values in the upper reaches, it is possible to satisfy shock waves' increased entropy conditions and restrain shock wave oscillations. On this foundation, he developed a type of NND form which did not have free parameters or wave movements. Recently, this has again been popularized to an even greater extent, being improved also in the areas of the reduction of blockage errors and standard principles of stability.

Before 1980, difference solution methods were, for the most part, opting for the use of displayed or open type methods, simple calculations, boundary conditions that are easy to handle, and appropriateness for use in vector operations. However, they had conditional stability and their solution times were also very long. Later, hidden type methods achieved a very great development. However, there still existed a number of problems which center differences had. At the present time, hidden type TVD forms are just being developed as well as research on speeding up convergence speeds, for example, LU resolution, Gauss-Sader (phonetic) iterative substitution, as well as Sidege (phonetic) flux splitting techniques, and other similar technologies.

TURBULENCE MODELS

This model is one that is needed to solve Reynolds average N-S equations. At the present time, the turbulence models that are used

are, for the most part, formulae for relevent experience obtained under noncompressible conditions. They are of a very limited nature. At the present time, quite a few new models have been developed, for example, zero equations, half equations, double equations, Reynolds stress simulations, and large scale vortex simulations, as well as other similar ones.

A widely used zero equation model is the Baldwin-Lomax algebraic model. This belongs to the equilibrium models. It is relatively simple. However, it is not good for calculating separation flows. Among the double or two equation models, one that is commonly used is the Lauden and Spalding $K-_{\varepsilon}$ model (K is the turbulence energy. ε is the dissipation rate.) Among non-equilibrium models, ones that are frequently used are the Johnson-King half equation model and two or double equation model. Large vortex simulations, because they are simple, are already widely used. Reynolds stess models, in theory, are even more universal. However, the equation set is too large. At present, it is difficult to get computers to take them. As a result, one has the most recent development of Reynolds stress and large vortex mixed models. The several models above, as far as the calculation of two dimensional problems is concerned, have already obtained gratifying results. As far as situations in three dimensions with compressible flows and relatively large back pressure gradients are concerned, they are also satisfactory. They are awaiting further development.

SUPERCOMPUTERS AND PARALLEL ALGORITHMS

In the past, CFD calculations, for the most part, were completed on single processers. Due to limitations on core chip speed, the more the speed is raised the more difficult it is. This should happen through the combined technical calculation operations of multiple computers. The key problem associated with this type of problem is software design, in order, as much as possible, to exert the capabilities of each processing device. The introductory software test produced by the Lanli (phonetic) center in 1989 by a combination of one VAX 750 and 14 VAX workstations is capable of making processor

utilization rates reach 95% or higher. One type of supercomputer test manufactured by West Germany is planned to have 250 nodal points. Late in 1989, floating point operation speed had already reached 6 hundred 40 million iterations/second. The project calls for it to reach 5 billion operations/second. The Ai Musi center plans to solve N-S equations on 16,000 processors. The calculating devices that Lanli is using in order to solve N-S equations have a total of 128 nodal points. The floating point operation speed at each nodal point is capable of reaching 5 billion iterations each second. If test productions are successful, it will be possible to solve complete N-S equations having 60 partial derivatives (for other situations, refer to specialized articles in this column in this No.).

KEY POINTS OF WORK TO BE DONE NOW

1. Confirmation of calculation programming. The future development of CFD progress and expansion is determined by simulation capabilities for complicated flow fields. However, this type of capability should be based on reliable experimental comparisons. In the past, testing was inadequate to be capable of being used in confirming CFD programming. In particular, there was a shortage of detailed data on flow fields for complicated exterior forms. The U.S. sees this work as extremely important. In 1986, NASA set up a specialized committee. It was tasked with directing and evaluating this work. In July of 1987, it called its first working conference. In the meeting, with regard to the confirmation of CFD programming for high supersonic speeds, it gave extremely great attention to it.

2. High Supersonic Speed Flow Field Calculations. This is, at the present time, one of the key questions in the development of space craft. The important difficulty with the calculations lies in problems of non-linearity and stability which are given rise to by strong shock waves, as well as in problems of true or ideal gas effects, and other similar questions. At the present time, there is a good deal of research concentrated on calculating the aerodynamic

characteristics of exterior forms similar to those of the X-30, as well as bow shaped waves on the nose section, and interference in the complicated wave systems of gas intake ducts. It is also directed at relevent equilibrium flows and flow field calculations for non-equilibrium ideal gases associated with limited chemical reaction speeds.

3. Turbulence Flow Model Simulation Research. At the present time, this has been taken in hand in two areas. The first one is the resolving of Reynolds stress average N-S equations. However, this requires having precise turbulence models. Another one is the resolution of complete N-S equations. However, the demands on computers are very high. The dimensions of grid dispersion should be of the same order of magnitude as the smallest turbulence flow vortex in the flow fields. At the present time, it is only possible to reach a number of the simplest results. Between these two types of methods, there is a type of approximation method associated with large vortex simulations. One first takes small votices, and, after filtering them out, solves for large vortex simulation parameters. After that, one takes small vortices and sees them as becoming isotropic. One uses models to display their movements. One readjusts the large vortex simulation field movements and, then, obtains approximations of trubulence flow fields. This type of method can be seen as having great promise.

4. Scientific Displays of Calculation Results. Currently, the imagery display contents for CFD results include isopleths and flow lines for flow field parameters. It is possible to use color depth changes to display changes in pressure and density. It is also 12(5)
possible to display dynamic processes associated with flow fields.

Above, we have concentrated on introducing difference method resolution techniques which have made progress and development in finite element, finite volume, and spectrum methods, as well as other similar methods. Limited by the scope of the article, however, we have not presented examples of each one.

WIND TUNNEL EQUIPMENT

New wind tunnel construction and the refitting of old wind tunnels is, at the present time, all concentrated on the raising of the dimensions of the testing section of low speed and transonic speed wind tunnels as well as test Reynolds numbers, increasing high supersonic speed simulation capabilities, developing CFD verification wind tunnels, and the initiation of research from the appropriate wind tunnels, as well as other similar aims. Below, we will take the U.S. as an example, and make a number of simple introductions.

The U.S. has already completed a 40x80 English foot wind tunnel refit (approximately 12x24 meters). The power has been increased from 27 megavolts to 100 megavolts. The wind speeds have gone from 100 meters/second to 150 meters/second. They have also added one 80x120 English foot (approximately 24x36 meter) new test circuit with wind speeds of 50 meters/second.

The U.S. has also newly constructed a high Reynolds number, transonic speed, continuous form, low temperature wind tunnel (NTF), using the injection of liquid nitrogen to lower the temperature of the tests' gas flows. The test section, which has dimensions of 2.5x2.5 meters can range its temperature all the way from normal temperature to 78^{O}K (-195^{O}C). The tests' M number range is 0.2-1.2. An M of 1.0 corresponds to a Reynolds number for a 0.25 meter length and is 120×10^{6}. It is equipped for full length simulation capabilities. Moreover, due to the fact that it is possible to separate dynamic pressures and the influences of M numbers, it is very appropriate for making aeroelasticity tests. The shortcomings of this equipment are that test expenses are extremely high, frameworks show vibratory movements, and the sensing devices inside the heating model are capable of producing model surface non-insulated wall problems.

The U.S. is putting together a project for a space plane. On the one hand, they are carrying out the appropriate refits on existing equipment. If it is made ready, this will raise the M number for test equipment to move the impluse engine forward from 4.5 to 6.0. At the same time, improvements have been made to the frame support system to make it automatically change angles of attack. On the other hand,

they have invested in the construction of a number of pieces of new equipment. For example, they constructed a 300-500 megawatt electric arc heating device and high supersonic speed electric arc wind tunnel, as well as fuel combustion heating test equipment, clean air heating test equipment, and magnetic fluid acceleration shock wave wind tunnels, as well as other similar projects.

The Kaersban (phonetic, possibly Carlsbad) Company's 96 English inch (approximately 245 cm) test section shock wave wind tunnel has not only made several dozen models for the X-30, with aerodynamic forces having M numbers of 10-18, as well as aerodynamic heating tests. It has also carried out large numbers of model tests on impluse jet engines with M 10-18. At the present time, they are still involved in refitting high pressure sections and model surface jet tubes in order to obtain high supersonic air flows with 1800 atmospheres of pressure at 12,000 K (11727°C).

The U.S. is still preparing a restoration and expanded construction of the Lanli (phonetic, possibly Langly) center's expansion tubes and expansion tube wind tunnel. In conjunction with this, they are preparing, in addition, a free piston driven section in order to increase capabilities. Rocketdyne Company has also prepared to construct a 120 meter long, national level Situoke (phonetic, possibly Stokes) tube in order to carry out full dimension high supersonic engine system tests for M from 12-25 as well as large dimension combustion tests in order to make precise determinations of engine capabilities under conditions of high enthalpy or heat content turbulence and the presence of chemical reactions. The U.S. has also prepared the construction of a 120 meter long electromagnetic projectile firing range. It is capable of firing 10 kg models at an initial velocity of 6 km a second.

CDF PROGRAMMING CONFIRMATION WIND TUNNEL

In November, 1984, Lanli (phonetic, possibly Langly) center constructed this wind tunnel. The dimensions of its test section were: 70 meters high, 100 meters wide, and 300 meters long. The speed was 67 meters/second. The Reynolds number for each meter was 0.4×10^6. The

degree of turbulence was only 0.05-0.08%. It is possible to make use of three different types of methods to carry out spacial flow field measurements: pitot pressure measurements with movements controlled by computer, flourescent steam screen, and laser instruments for measuring speed. The exterior diameter in the dimensions of surface layer measurement tubes was only 0.05 (illegible) cm. The interior diameter was 0.033 cm. The wall thickness was only 0.0127 cm. Use is made of the ball tipped 5 hole probe, with a diameter of only 0.317 cm, to measure flow field pitch, flight deviation, and total pressure. The pressure scanning valve's accuracy is 0.1%. When changes in temperature are greater than 2°, it is also capable of automatic calibration. This is a wind tunnel specially manufactured to verify CFD programming. Fig.3 is a comparison between the calculated results and the measured pressures for a 75° triangular or delta wing.

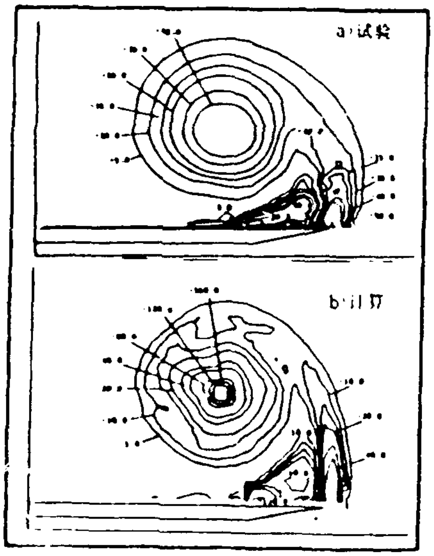

Fig.3 A Comparison of Test Results and Calculations for the Lanli Center wind Tunnel for Verifying CFD Programming (75° triangular wing, angle of attack 20.5°, Rn 0.5×10^6)

WIND TUNNELS WITH AUTOMATICALLY ADJUSTING WALLS

During the past more than ten years, a large amount of work has already been done in the area of automatic wall adjustments of test sections in two dimensions. However, as far as three dimensional tests are concerned, because flow lines are relatively complicated, it was necessary to go through an arrangement of four wall surfaces in order to put out a flow field space which did not have interference. The difficulty was relatively great. In the period 1982-1984, there were people who brought up the concept of making use of arrangements of the two top and bottom walls as another possible way of working the three dimensional tests. Actual execution clearly showed that it was only necessary that the model be symmetrical about vertical planar surfaces and that its dimensions be smaller than 0.65 of the width of the tunnel. Tunnel wall interference was primarily concentrated in the central area of the test section, and this type of method was, then, very effective. At that time, the amount of interference remaining in the direction of the display is a small one. It is very easy to rectify it through calculations. As a result of this, new hope was brought to the practical application of automatically adjusting three dimensional walls.

It is particularly necessary to point out that, recently, inside China and outside, people have been in the midst of developing a type of wall pressure information method. That is, going through measurements of pressures in the central areas of wall surfaces. Through computational elimination of tunnel wall interference, it is possible to figure it as a type of "soft" automatic wall adjustment technique. This type of method is very appropriate for tests with large angles of attack. In recent years, it has also spread to tunnel wall interference calculations for flows around blunt bodies.

WIND TUNNEL TEST TECHNIQUES

Due to high speed data collection and processing systems, electronic scanning valves and computers, advanced measurement display devices, and improvements in flow fields, the level of wind tunnel tests has experienced a very great lifting up. Testing capabilities

have been expanded. The amounts of information obtained have grown large. Expenses have dropped. Quality has gone up. In particular, there has been, in the measurement technology of continuously changing angles of attack, in the technique of having a number of scaies make simultaneous measurements during a single test, and the technique of carrying out a number of different types of measurements during one test, as well as other similar techniques, a very great shortening of the time period for data collection and an increase in the amount of information measured at one time. Besides this, the utilization of remote control surface techniques reduced the time for changing model rudder surfaces and raised testing capabilities. In pressure measurement tests on the C-17, there were 1500 pressure measurement points all together and 15 remote control surfaces.

Wind tunnel tests with large angles of attack, in recent years, have developed relatively fast. The AEDC 16 English foot (approximately 5 meter) transonic speed tail boom pushed into wind tunnels at large angles of attack, in one test, is capable of continuously changing 50°. Moreover, it maintains the location of the model in the wind tunnel basically unchanged. The overall range of changes in angles of attack is from 20° -- 87°. The AEDC's 4 T wind tunnel is also capable of taking a controlable track technique and using it in interference tests on two bodies as well as measurements of aerodynamic characteristics associated with configurations of large angles of attack and stalls. At the present time, inside China, FL-24 wind tunnels at aerodynamic centers are also fitted with sets of this equipment.

The work of high supersonic speed wind tunnel measurements, from the 1960s onward, has already had quite a great development. Laser techniques have been a very great impetus to high supersonic speed diagnostic techniques, laser Doppler speed instruments and spectrum devices, laser induced flouresence measurements, and Laman (phonetic, possibly Raman) interference spectrometers, and other similar techniques, for each of which it has had its own particular advantages. In the area of measurements of flow field densities, by contrast, successful use has already been made of laser holographic measurements and hologram...(cont'd page 61)

AERODYNAMIC RESEARCH BY THE BEIJING AERODYNAMIC RESEARCH INSTITUTE

Zhang Zhangjie Cui Erjie

The Beijing Institute of Aerodynamics began construction in 1956. It was New China's first comprehensive aerodynamic research and testing base. It takes responsibility for basic aerodynamic theory. It also takes charge of the aerodynamics of craft for aviation and space flight, industrial aerodynamics, and other similar applications in many areas of research and testing.

The research institute currently has four departments. The theory department primarily handles the theory and applications of aerodynamics, calculated aerodynamics, as well as the test production of software, and so on, and so on. The testing department primarily takes care of low speed, transsonic speed, supersonic speed, and high supersonic speed wind tunnel tests, electric arc wind tunnels, electric arc heating devices, and water tunnel tests, as well as related research. The measurements and control department primarily handles the test manufacture of scales, sensor devices, and optical instruments, estimates or measurements research, and research on the automation of controls. The fluid engineering department primarily takes care of industrial aerodynamics, the test production of aerodynamic ground simulation equipment, as well as the development of fluid engineering projects, and other similar items.

The research institute currently possesses 13 pieces of wind tunnel equipment and heating devices of various types. It has one each of standing type wind tunnels and prone type water troughs. All the main equipment embodies automated measurement controls. It is capable of obtaining test data and curves in a real time manner. Besides this, laboratories are also fitted with hot line and hot membrane wind speed instruments, laser instruments for measuring speed, optical flow field measurement systems, and numerous types of flow field display equipment, as well as imagery processing systems. (A picture of the relevent equipment can be see by consulting Fig.(unclear) 3).

Our institute, besides taking responsibility for the task of model testing, also, for the development of aircraft pre-research work, formed a complete set of engineering calculation methods, design calculation handbooks, as well as empirical formulae which take experimental data as their foundation, and related analysis methods. The use of several dozen classical arrangements clearly demonstrates that calculation precision satisfies engineering design requirements.

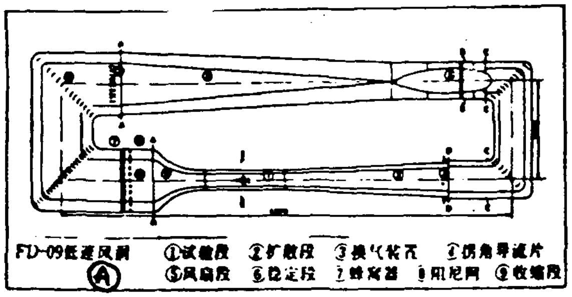

Fig.1 A Schematic Diagram for the FD-09 Low Speed Wind Tunnel of the Research Institute (A) FD-09 Low Speed Wind Tunnel (1) Test Section (2) Expansion Section (3) Air Exchange System (4) Corner Flow Guide Plate (5) Wind Fan Section (6) Stability Section (7) Honeycomb Device (8) Damping Net (9) Contraction Section

In recent years, pre-research work has been concentrated on advanced aerodynamic arrangements, including high lift to drag ratio supersonic cruising arrangements or layouts, side strip wings, closely paired duck types, wing fuselage fusion bodies, and other similar studies. One has also seen carried out the unification of wing-fuselage-engine structural forms as well as using auxilliary excitation equipment and perturbation methods to reduce or eliminate large angle of attack non-symmetrical vortices and lateral force research. All of these achieved different degrees of results.

In order to match the needs of the next generation of aircraft for research on large angle of attack flow fields, our institute, at the same time that it was developing flow field display techniques, also developed a number of engineering estimates and numerical value calculation methods, for example, models that opt for the use of stripped body vortical surface models and improved iterative substitution methods of calculating flows around isolated wings at large angles of attack. On the basis of dispersion vortex models for long thin objects, we simulated combined wing-fuselage bodies as well as vortical interference and amalgamated or merged processes. Our institute's vortex lattice method program is already capable of being used in vortical calculations for wing surface separations and vortical interference analyses for a number of complicated exterior forms (side strip wings, close paired duck wings). In recent years, the vortical lattice method of calculation techniques has been advanced a step further, as have been convergence characteristics, causing the efficiency of calculations to be raised one fold or more.

As far as a number of the "grandfather" problems in the test manufacture of aircraft are concerned, progress has also been made. When calculating the total dynamic efficiency for wing surfaces and rudder surfaces, one takes the normal pressure surface element methods and independent wing calculation methods for large angles of attack associated with experimental data and puts them together. Making use of the "equivalent angle of attack" concept, one gets the estimated calculation method vector forces and the hinge moment of force method. In conjunction with this, people have already expanded into complicated planar surface configurations, and one is capable of considering separation vortices on the nose, concentration vortices rear of the wings, as well as fuselage interference, and other similar factors.

In the area of adding in externally suspended objects, a type of complete program has been developed which is capable of calculating mother craft flow fields, the forces and moments of force which are experienced at each of the various points in interference flow fields with externally suspended objects added in, as well as the operational tracks of the externally suspended objects. In the calculation

programs for fuselage flow fields, it is possible to do calculations of air intake path effects as well as fuselage-suspension frame-suspended object interference effects. In conjunction with this, in calculations, one opts for the use of the rate of inclination of lift force lines obtained from experimentation. As far as lateral drag and axial force parameters are concerned, classical examples of calculations clearly show that this type of handling, for the most part, raises the accuracy of calculations of the influences on aerodynamic forces of flow field non-uniformity effects in the process of suspended object separation. The results are reasonable and reliable.

In the area of calculations of aircraft friction drag and heat flow, making use of calculation methods which are already relatively familiar and putting them together with experimentation is a help in making simple comparisons between the forms of momentum-energy relationships. In the correction for compression effects and the influence of degrees of coarseness, "related parameter methods" have already been developed. It is possible, under very broad exterior flow conditions, to carry out calculations. In conjunction with this, use was made of the test results from thousands of calculations, and decisions were made to select the imaginary origin point to act as the turbulence flow origination point, to select a matching type of Reynolds number comparison, on the handling of turning areas, on flat plate and conic surface area friction drag, as well as transformation relationships associated with heat flow calculations, and other similar questions. As a result of this, a complete set of calculation methods has been formed possessing accuracy for actual engineering use.

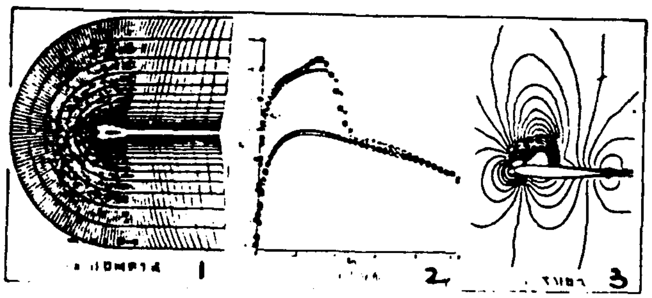

Fig.2 Classical Results from Finite Difference Method Calculations Used in Research (1) (illegible) Grid Formation (2) (illegible) Force Distribution (3) (illegible) M Number (illegible)

Our institute's research on the calculation of aerodynamic forces has developed gradually together with the needs of the test production of aircraft. The work involved various individual iterations of layers simulated directly from numerical values solved for in N-S equations on a finite basis from linearized potential equations.

In the arena of surface element methods for subsonic and transonic speeds, our institute has already set up normal pressure calculation programs for stand alone aircraft wings and wing-fuselage-tail section composite bodies, as well as practical engineering programs for calculations of the various types of non-circular cross sections, wing-fuselage fusion bodies, and the various types of non-continuous wing surface configurations associated with sides and edges.

In the area of the solution of transsonic speed potential equations, we have studied and decided on the initial field selection in the iterative substitution process as well as questions related to convergence characteristics of results. We have set up calculation programs for small perterbation potential equations mixed with difference linear relaxation iterative substitution solution methods and full potential equation rotation difference forms.

In viscous/non-viscous interference solution methods, we opted for the use of potential equations and Euler equations to describe non-viscous flow fields. With normal and inverse solution methods for adjacent surface layers, there was a mutual matching up, as well as iterative substitution solutions. We obtained viscosity flow characteristics with the presence of shock wave interference and partial separation on object surfaces. Going through transsonic speed flow field calculations for a number of wing forms, it was clearly shown that this type of method, which involves calculating viscous interference, clearly shows improvement in shock wave location and pressure force distribution characteristics.

In Euler equation numerical value solutions, we set up calculation programs which are capable of distinguishing small, medium, and large angle of attack flow fields. As far as the complicated exterior forms for angles of attack of 20° or less are concerned, we opted for the use of multiple increment calculation grids which were generated by rotation and preserved angles. These guaranteed the orthogonality of the grids. In the case of wrap-around flows for large angles of attack, we opted for the use of models similar to those outside of China. Using storage tower conditions, we simulated the separation vortices for large angles of attack on forward edges and leeward surfaces. In order to resolve problems with calculations of supersonic speed flows in localized subsonic areas, in the late 1980's, we also began the development of applied research related to non-steady state difference methods. We have already achieved definite progress.

In work with numerical value solutions to N-S equations, the principal things are research into difference forms, numerical solution methods, the quickening of the speed of convergence, as well as the raising of the degree of accuracy, and other similar areas. In conjunction with this, making use of the accomplishments that were achieved, we carried out numerical simulations, one after the other, on the generation and development of blunt body wrap-around flows and turbulence flows, interference of separation flows and surface vicinity layers, air intake ducts and interior flows, as well as other similar problems.

In the areas of numerical simulations of two dimensional wing forms and three dimensional aircraft wings, we opted for the use of different simplified degrees of N-S equations and appropriate turbulence flow models, numerical value generation of calculation grids, and set up a complete set of calculation programs. As far as the results of calculations for wing forms and aircraft wings such as the NACA0012 and RAE2822, as well as other similar wings are concerned, they clearly show that they are exceptionally close to the empirical data (Fig.2). At the present time, this method is just in the midst of research and development to make it capable of expanding its applications into large angles of attack and even higher Re numbers.

Our institute, on the foundation of taking charge of conventional testing, also began development of multiple types of non-conventional test techniques, including low, trans, and supersonic speed chattering, determination of vibration boundaries, half mode and full mode hinge moment force tests, air entry path and jet flow tests, tests on the release of externally suspended objects, parachutes/ejection life saving, ground surface effects, and aerodynamic noise measurements, as well as other similar items.

In the area of dynamic derivative testing, progress has been relatively great. One after the other, successful test production has been done on half mode and full mode pitch dynamic derivative, tail support rod rolling and turning vibration, and continuous rolling and turning movement derivative scales or balances, as well as tail support rod pitch/flight deviation free vibration and forced vibration scales or balances, full mode time difference dynamic derivative scales or balances, three free movement degree stability test equipment, and static and dynamic combined scales or balances, as well as other similar items, for several dozen types of dynamic test equipment. Due to the large amount, we opted for the use of gas float techniques, internal type vibration excitation and operating techniques, non-contact type induced synchronizer devices, optical raster code disc and optical fibre angular code, as well as other new types of measurement techniques. The injurious drag of the equipment itself has been greatly reduced, and the accuracy of test measurements has been greatly increased.

In tests at low speeds with large angles of attack, we developed a type of backward mounted tail support rod structure. Through two perpendicular hanging connector rods and a structure outside the tunnel walls connected up, we realized changes in angle of attack and angle of side slip, structural simplification, and solidity, as well as a reduction in the amount of intference. Moreover, we guaranteed that the model reference point was located on the center line of the wind tunnel, and reduced the amount of rod interference.

In tests of externally suspended releases, we had to release the model using metal wires hanging in the center of the wind tunnel. After a stable flow field was set up, the suspension line was cut. Again, we used high speed photography to record the track of the release. In conjunction with this, use was made of parameter distinguishing methods to solve for and obtain the effects of aerodynamic forces on objects. The methods in question have already achieved multiple instances of success.

In flow field display techniques, besides being able to make use of a number of conventional methods, we also independently developed types of laser-smokescreen and laser-steam screen methods. These are used in order to display various types of vortical flows and complicated interference flow fields. They are capable of achieving clear, detailed flow field structures, rotating vortical paths, and various other similar types of flow configurations, as well as shock wave induced separation imagery. In conjunction with this, one puts together computer imagery processing and techniques for the three dimensionsal overlay and buildup of multiple cross section imagery, setting up a spacial structural image of the shape.

BASIC RESEARCH

Questions which have a relatively direct relationship between this area and the test production of aircraft are:

The Mechanism of Vortical Breakup. Starting out from simplified N-S equations, one sets up vortical core motion equations to solve. Going through an analysis of changes in such parameters as speed, pressure, vortical magnitude, and so on before vortical breakup or rupture and of vortical magnitude transmission characteristics, one is presented with the influences and effects of speed gradients, viscosity dissipation, compression, and other similar factors on the process of vortical breakup.

Non-Steady State Increases in Lift. Making use of the simple resonance or aperiodic oscillation of wing forms, leading edge or trailing edge perturbation flow plates, dynamic boundary effects and

characteristic designs associated with stationary vortical strengthening systems, as well as other similar methods, in controling flow movement separations and rotating vortex tests, people have already achieved clear aerodynamic gains. Transient lift increased several fold, and time averaged effects were also unusually clear.

Research on Drag Reduction. The primary research is into drag reduction mechanisms associated with non-conventional sine wave form walls and soft, smooth walls. Initial results clearly show that appropriately controled ripple or corrugation height/wavelength ratio, wave height, wave length, and object surface curvature radius/laminar surface thickness ratios of rippled or corrugated walls are capable of clearly reducing drag.

Shock Wave-Surface Laminar Interference. For many year inside China and outside, although widespread work has been done on these questions already, quantitative research, however, as well as control studies on interference, are still very inadequate. Our institute, in supersonic speed as well as high supersonic speed air flows, opted for the use of different forms of shock wave generating devices. Under controled conditions of laminar surface interference, measurements were made, inside the interference areas, of static pressure, heat flow distribution, pulse pressure distribution, as well as power spectrum density characteristics. In conjunction with this, for surface and near wall flow states, we carried out detailed displays (Packet 3, Fig.7). We analyzed interference effect formation mechanisms and influencing parameters. The results supplied a foundation for the improvement of interference area localized flow fields as well as carrying out active and passive control of shock wave induced surface laminar separations.

Surface Laminar Turning. We opted for the use of uni-directional amplification ripple shadows and a spark gathering focus cathode shadow technology to carry out laminar surface observations. The former is the taking of surface layers and amplifying them along the direction of their thickness. It is capable of clearly displaying surface laminar development status and turning areas (Packet 3, Fig.6). The latter, by contrast, relies on the strong instantaneous power of pulse light sources to obtain surface layer images. It is

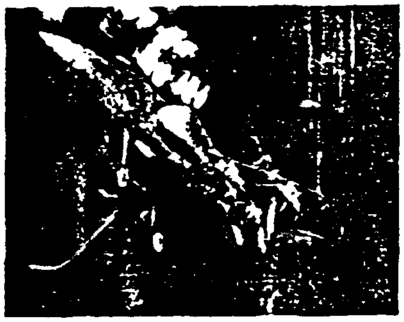

Fig.3 Research Institute Carries Out Ground Surface Effect Wind Tunnel Tests

also possible to determine turning areas. Besides this, we also used surface heat flow distribution measurements as well as pulse pressure measurements and other similar methods to determine the turning points of smoot' wall surfaces. The results were in line with tests of a similar type outside of China. As far as the coarseness surface turning point problem is concerned, after we went through research, it was discovered that, after the height of coarseness elements reached a certain value, its perturbations determined effects on turning points. Going through large amounts of testing, we decided criteria for determining turning points.

RESEARCH ON COMPLEX FLOWS BY THE INSTITUTE OF FLUID MECHANICS OF THE BEIJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS

Deng Xuejin

Complex flows, in the subject of aerodynamics, take strong interference between viscous flows and non-viscous flows as well as stong coupling to act as their basic special characteristics. Moreover, in mathematics, one sees demonstrated the high degree non-linearity of the flow control equations for them as well as the linear nature of the special aerodynamic characteristics. Complex flows are the cutting edge field of research in the study of aerodynamics at the present time. The Beijing Aeronautical Fluid Mechanics Institute, from the 1970's onward, has carried out broad, systematic, and penetrating research into the laws for changes in complex flow phenomena, flow structures, and aerodynamic characteristics, as well as empirical research techniques and calculation techniques.

RESEARCH INTO SEPARATION FLOW AND VORTICAL MOTION

1. Research into three dimensional separation flow's basic phenomena, separation criteria, and modes or types, in the midst of opening up research into separation phenomena, brought up the fact that the starting point for open separation is the point of view of the high order semi-singular point S'sN for cross sections in a state of flow. During research on the formation mechanism of rotational vortices, the separation type or form for saddle point/rotation point types were given. In conjunction with this, it was also pointed out what their effects were in the formation of rotational vortices. On the foundation of deep research into Lighthill three dimensional separation types, we were given another necessary condition for three dimensional separation $(\frac{\partial \tau x}{\partial x}+\frac{\partial \tau y}{\partial y})<0$.

2. Research into vortical breakup phenomena and special characteristics involved the first ever test production in China of vortex generating devices associated with research into vortical breakup phenomena. Making use of dyed fluid displays and laser speed measurement techniques, we studied two types of formation conditions for breakup phenomena and the corresponding speed distribution cross sections. In conjunction with this, we discovered that harmonic wave oscillation is capable of delaying vortical breakup phenomena. In engineering research on the aerodynamic layout of aircraft, we also investigated deeply into the effects on wing vortex breakup of the mutual interference between body vortices and wing vortices.

3. Research into the vortical interference systems of aircraft layouts probed the mutual interference phenomena and corresponding development processes between the side strip vortices and outside wing vortices of side strip wings and dual triangular or delta wings. During tests of missile models with large angles of attack, they took the interference phenomena between body vortices and wing vortices with the same direction of rotation and summed them up into three classes: phenomena induced by the mutual drawing close together of body vortices' vortical cores and wing vortices' vortical cores, twining phenomena associated with the mutual turning together of body vortex vortical cores and wing vortex vortical cores, as well as vortical agglomeration phenomena associated with the amalgamation of two vortices. They also did further studies of influences of these interference phenomena on vortical rupture or breakup. Besides this, they also studied forms with equal curvatures, forms divided into sections, and step forms as associated with the vortical characteristics of flap vortices as well as their effects in reducing drag. They brought out appropriate control deflection angles for forward edge flaps and rear edge flaps in order to control and make use of advantageous interference between vortices which leave the body so as to raise the drag reducing effects of vortical flaps.

4. As far as studies of numerical value methods as associated with separation phenomena and vortical motion are concerned, because, in large dimension flow movements under high Reynolds numbers, the vortical magnitude that floats up at the point of separation is

limited to within thin layers in the vicinity of walls, separation vortical areas are large scale vorticity distribution areas. As a result of this, with regard to areas with different scales, they opted for the use of partial area Lagelangei (phonetic) vortex methods to respectively use surface laminar or boundary layer equations and N-S equations to carry out numerical value handling. As a result of this, there were very, very great savings of computer time and internal storage. It was possible, on the IBM-4341 model computer, to calculate out the cylindrical, instantaneously initiated early stages of flow structure.

5. As far as engineering calculation model studies of wrap-around vortical flows which leave the body on the forward edge of aircraft wings are concerned in order to take the simulations of the forward edge vortices which leave the body and make them even more precise, on the basis of the normal vortex diffusion line, we increased and concentrated vortical core models as well as vortical core roll up and absorption effects. The calculation results from making use of this type of model and the solutions of N-S equations are in relatively complete agreement.

SHOCK WAVE/BOUNDARY LAYER INTERFERENCE RESEARCH

1. As far as back swept shock wave and turbulence flow boundary layer interference research is concerned, in this type of interference, there exist two types of interference--cylindrical form and conical form interference. They both possess quasi-two-dimensional characteristics. However, in terms of scale, they are not the same as two dimensional interference. We went through consideration of lateral flow effects, taking cylindrical form interference which possesses quasi-two-dimensional characteristics and making mutual relationships with two dimensional interfernce in terms of scale.

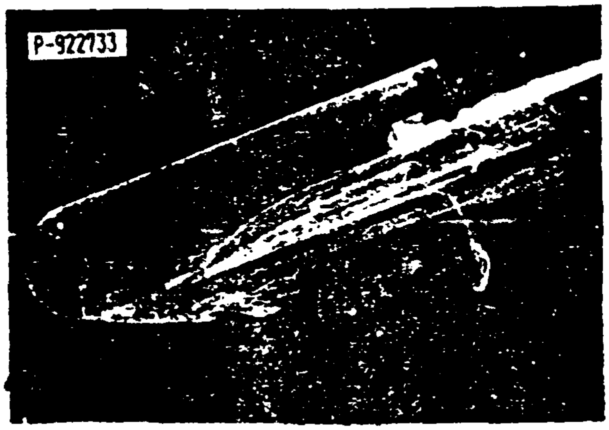

Fig.1 Making Use of Object Surface/Spacial Relation Display Techniques, Display, With Large Angle of Attack, of Nose Section Separation Phenomena in Wrap-Around Flows and Their Vortical Formation

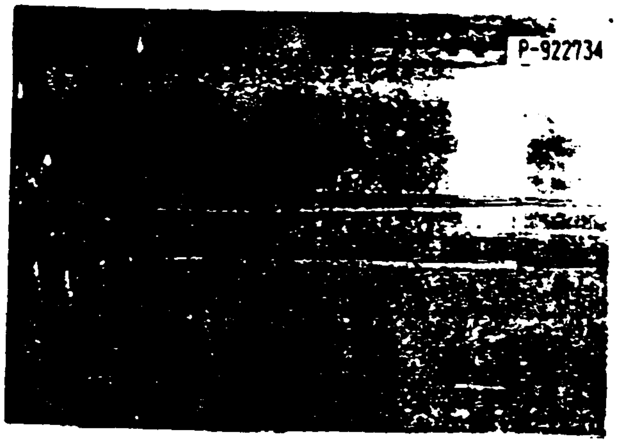

Fig.2 Bubble Form Breakup Configuration as Displayed in Vortex Generating Device

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2. As far as back swept shock wave/boundary layer interference Mach number reactions are concerned, it was discovered that, in back swept compression angle interference flows, the cone/column interference boundaries will follow increases in Mach numbers and move toward the column type area. The interference area's normal directional scale will also follow reductions in Mach numbers and increase. Besides this, in the Fluid Mechanics Institute, they have

recently also begun the development of passive control research associated with transsonic speed shock wave/boundary layer interference, causing aircraft wing form interference drag forces to be greatly reduced.

RESEARCH ON INTERFERENCE BETWEEN VECTOR JET FLOWS AND MAIN FLOWS

1. As far as research on air blown in the direction of development is concerned, in the early 1980's, the Flow Mechanics Institute, throughout China, led the initiation of development in experimentation on air blown in the direction of the development of aircraft wings. It probed different interferences between conventional air blown in the direction of development and air blown in the direction of development of the forward edge as related to the main flow as well as into the mechanisms forming interference vortices associated with different jet flows/main flow.

2. As far as research into interference between vector jet flows associated with binary or dual jet tubes and main flows is concerned, in the "7-5" period, development was begun on this item of research. The results showed clearly that the interference flow movements between binary or dual jet tube vector jet flows and main flows strongly depend on the configuration of the actual set up. With regard to conventional wake jet forms, before the rupture or break up of separation vortices on the forward edges of aircraft wings, interference between vector jet flows and main flows is weak. Flow movement phenomena in wrap-around flow fields and flow field structures have very large influences. However, in flow movements at large angles of attack after vortical rupture or break up, vector flow jet/main flow interfernce effects are capable of delaying the rupture or break up of forward edge vortices that leave the body.

3. As far as research on the numerical value simulation of interference between jet flows and main flows is concerned, there has been a development of Euler equations to solve calculation methods for interference flow fields between supersonic speed jet flows and

supersonic speed main flows. On the foundation of the utilization of self-adjusting grid algorithms, a selection was also made of partial area lattice form methods. In areas where flow alterations are gentle, use is made of the traditional binary or dual shock wave capturing lattice form. However, in areas where changes in flows are abrupt, by contrast, one switches to the use of TVD lattice forms. In this way, it is not only possible to accurately capture complicated shock wave systems as well as various types of other characteristics, it is also possible, moreover, to raise the efficiency of calculations over a broad range.

4. As far as research into the structures of flows in vector jet flow/main flow interference is concerned, use is made of display techniques associated with dyed fluids in water troughs or tanks. Research was done on alterations in interference flow structures and development processes, including vector jet flow track deviations, penetration depths, and the formation and development of back vortices in jet flow spaces. Besides this, research was also done on mixing effects between binary or dual jet tube vector jet flows and main flows.

RESEARCH ON COMPLEX FLOW PHENOMENA DISPLAY TECHNIQUES

1. As far as research on oil flow display techniques and flow spectra analysis is concerned, the first ever application in China of singularity point topological theory analysis of oil flow spectra diagrams has caused the traditional oil flow display techniques to become a powerful tool for research on and analysis of complex flow phenomena. This type of flow spectrum analysis method is already widely used in a number of studies on complex flows. A particular example of this is the studies on flow forms associated with the advanced aerodynamic lay outs of aircraft and the recent simplification of space planes, where it achieved excellent results.

2. As far as the technique for displaying the combining of object surface and spacial flow fields is concerned, it is a display technique which makes use of water tunnel studies of complex

flow field phenomena. Before testing, on the surfaces of experimental models, a certain amount of display dye is painted. Following along with complicated separation wrap-around flow movements, these dye materials not only, on the surface of the objects, form dye colored lines similar to the oil flow spectra, the dye colored fluid, moreover, follows along with the aerodynamic separation, and enters the interior of the fluid, very clearly displaying the development of separation shear layers and the formation of vortices.

3. As far as research into spacial flow field display techniques and numerical graphics processing methods is concerned, on the foundation of the utilization of laser chip optically displayed spacial flow fields, further development was made of spacial flow field qualitative analysis techniques. For example, when studying the mixing effects of binary or dual jet tube vector jet flows, a choice was made for the use of laser chip optically displayed cross section flow movements of spacial jets. Through digital or numerical imagery processing, it is possible to carry out qualitative studies of concentration fields in vector jets.

4. As far as the test manufacture of large model water tunnels is concerned, the Fluid Mechanics Institute's large model water tunnel, as designed for test manufacture in the "7-5" period, will be put into use in the "8-5" period.

A TYPE OF NEW MODEL EXCITER SYSTEM USED IN RESEARCH ON AIRCRAFT CHATTER

Zhu Shouxin

Research on flight chatter is an indispensable link in projects for the test production of aircraft. At the present time, excitation methods used in the study of chatter belong primarily to the six types below.

The Control Stick Overload Method. Pilots go through control stick manipulation causing each control surface to produce pulse motion. This type of method is simple. However, it is not capable of exciting the relatively high frequency states required for chatter.

Atmospheric Turbulence Method. As far as aircraft in flight in turbulent flows in the atmosphere are concerned, turbulent flows take a continuous, random form, exciting relatively low frequency states of structural chatter. This type of method has been used right through the chatter testing of such aircraft as the F-111, the F-16, and the X-29. However, the number of flights required is very expensive. Moreover, frequently, because of a lack of turbulent weather, tests are delayed. Also, there is no way to carry them out at the same time as the majority of other test projects, which do not require turbulent weather conditions.

Programmed Control Input Methods. As far as the carrying out of programmed control input on flight control systems is concerned, one makes use of rudder surface vibrations in order to excite chatter. This method has already been used on such aircraft as the F-15, F-16, and F-18, and control surface brakes are capable of exciting high frequency vibration states in fuselages. However, the design of the brakes on the control surfaces of the majority of aircraft cannot take this type of high frequency vibration.

Inertial Excitation Methods. This and the aerodynamic blade or vane and fireworks methods all belong to exterior excitation forms. Inertial excitation devices normally, on a rotating shaft, install an unbalanced weight. The shaft is driven by a variable speed electric

or hydraulic motor. Another type is a vibrating mass activated by a servo operated electro-hydraulic brake. This type of method, in high frequency ranges, is very effective. However, the mass required in low frequency ranges is very large. As a result of this, it will change the aircraft's vibratory state or mode. Chatter tests for the B-1, F-14, BAe-146, and "Concorde" supersonic aircraft all made use of these methods.

Aerodynamic Vane Method. On aircraft, it is possible to effectively excite the vibrating sections of structures which influence chatter, for example, the tip sections of fuselage wings and tail wings, installing lifting surfaces, going through vibrations of them and obtaining vibratory excitation forces. This type of method
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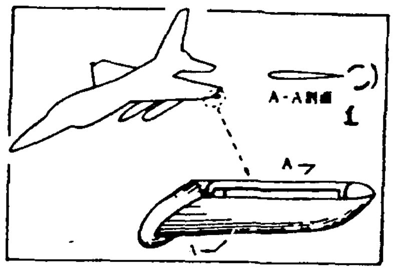

Fig.1 Installation of a New Model of Vane Exciter Device on Wing Tips
(1) A-A Cross Section

is capable of producing adequate excitational motive forces. However, it requires appropriately large amounts of power in order to overcome aerodynamic forces and inertial loads. Because of this, the driving apparatus is complicated. This type of excitation device has already been used in the test production projects for such aircraft as the DC-10, L-1011, B747, A310, the A-10, and other similar aircraft.

The bonker method. When this type of small model firework rocket system fires, it is capable, within a short period of time, of producing a pulse of force. This method is made use of a relatively great deal in Europe. It is primarily used in tests in which the test conditions vary greatly with time. This type of equipment is light in weight, small in size, easy to install, and requires little power. However, its drawback is that the pulse it produces is not capable of taking energy and concentrating it within a certain control frequency range. In each instance, the flight test points are very limited. Moreover, the pulse characteristics vary with the test environment.

From among the various types of methods discussed above, it is possible to see that they all have existing in them different degrees of shortcomings. In order to develop a type of even better excitation system, a dynamics engineering company test produced a type of new model aerodynamic vane type exciter device. This system has a fixed aerodynamic vane. Its rear edge has installed on it a rotating type round tube with an open slit (Fig.1). The open slit on the round tube is one that follows in the direction of the development of the wing. When the round tube rotates, the air flow will then, by turns, alternate in going up and down. This produces twice the periodic

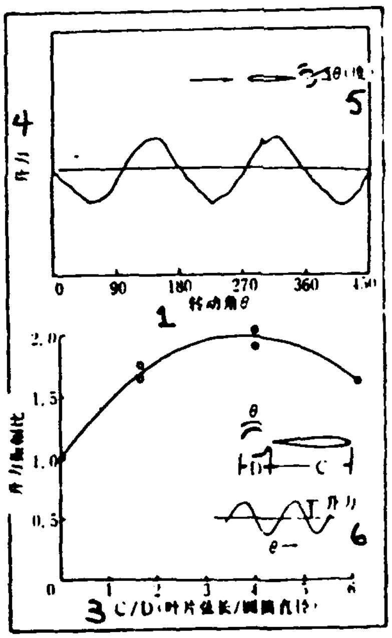

Fig.2 (Top) Changes in Static Lift Following Rotation Angle of the Round Tube (Bottom) The Influence of Vane Chord Length on Vibration Lift Amplitude (1) Angle of Rotary Motion (2) Lift Amplitude Ratio (3) C/D (Vane Chord Length/Round Tube Diameter) (4) Lift (5) Degrees (6) Lift

lift associated with the rotation frequency of the round tube. Adjusting the frequency of rotation of the round tube, it is then possible to change the frequency of excitation. Moreover, the amplitude of the excitation force and the dynamic pressure of the air flow form a direct proportion. Changing the degree of opening of the slit in the rotating tube (magnitude), it is then possible to alter their magnitude.

This system can be driven by a small model D.C. motor. The driving system is capable, together with the vane and round tube assembly, of forming an independent, self-sufficient chatter excitation system, installed at any time at selected positions on the aircraft. Moreover, this is not similar to other methods which, because their required power is great, have no other way but to take the system and attach it into the hydraulic system of the aircraft.

The new model of vane excitation device is generally installed on

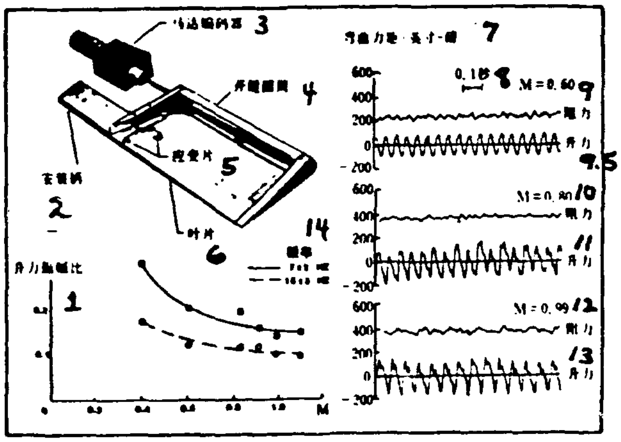

Fig.3 Changes Over Time in the Moments of Force of Three Dimensional Models Used in Transonic Tests and Normal Directions and Chord Directions as Well as Changes in Vibratory Amplitudes with Changes in M Number and Frequency. (1) Lift Amplitude Ratio (2) Installation Handle (3) Motor Encoding Device (4) Round Tube With Open Slit (5) Strain Plate (6) Vane (7) Moment of Curvature (English Inch-Lbs) (8) Seconds (9) Drag (9.5) Lift (10) Drag (11) Lift (12) Drag (13) Lift (14) Frequency

aircraft at positions with vibrational modes that are capable of evoking interest. For example, they are installed on wing tips. At this time, two excitation devices are capable of driving in phase with each other or in reverse phase 180° out in order to excite symmetrical and antisymmetrical vibrations. This system is capable of

producing sine form vibratory lift. Its amplitude and frequency are appropriate to the exciter forces produced by vibration flaps with the same dimensions. However, the power it requires will be much smaller. The reason for this is that the round tube rotates at an almost constant speed. The moment of balanced inertial or momentum forces of the high frequency vibration vane excitation method does not exist. On flap rear edge rudder surfaces, the aerodynamic hinge moments are very great. Moreover, the lateral cross section of the round tube is a round form wall surface. All pressure forces are acting along the radial direction. They do not produce moments winding around the axis of rotation. Because of this, the moment of force of the powering motor of this type of new model system only overcomes mechanical or aerodynamic friction forces.

In order to experimentally verify the feasibility of this system, this company carried out a series of low speed and transonic speed tests. In static tests done on a two dimensional model in a small model wind tunnel, measurements were done on the relationship of static lift forces and the angle of rotation of the round tube. The results are shown in Fig.2 (top). In order to specify optimizations for vane chord lengths and the diameter of the round tube, use was made of vane composites consisting of the same round tubes and different chord lengths of vanes to carry out static tests. Fig.2 (bottom) shows changes in sine form lift amplitude elliptical tube lift. It is possible to see that the optimum ratio is between 3-4. The lift parameter change based on the overall chord direction dimensions (round tube diameter plus vane chord length) is $\pm$ 0.35.

In order to do research on the influences of M numbers and non-steady state aerodynamic forces, in a Luokexideqiaozhiya (phonetic, possible Lokeshidechev) wind tunnel, transonic speed dynamic testing with M numbers up to 1.1 was carried out on three dimensional models. The length of the model spread was 20.32 meters. The chord length was 12.70 meters. The vane opted for the use of a water chestnut shaped wing with a thickness of 10% (Fig.3). The round tube uses a variable speed 20 Watt D.C. servo motor for the drive. The ratio of the vane chord length and the round tube diameter, on the basis of the optimization range of Fig.2, was taken as 3:1.

In situations where the M number is 0.60, 0.80, and 0.99, measurements were taken, respectively, for changes over time in the moments of curvature. Because the vane angles of attack were zero, the measurements, as a result, obtained moments of curvature in the normal and chord direction as well as moments of force for lift and drag which were the same. The results clearly show that changes in dynamic lift are primarily non-steady state forces. The moments of force caused by them, as compared to drag, possess even more a sinusoid characteristic (Fig.3 (Right)). Besides this, measurements were also made of normal direction excitation frequencies. Under conditions where they were, respectively 7 ± 2 Hertz and 15 ± 3 Hertz, the relationship of amplitude values between peaks for moment of lift force parameters and M numbers was also measured. The results of the experiments clearly show (Fig.3 (Right)) that excitation amplitudes follow increases in M number or frequency and decrease. Exciter devices generally are installed on the the wing tips of the fuselage wings or the tail wings, that is, the places where wing tip vortices are capable of generating relatively large changes in the local average aerodynamic flow direction. Because of this, it is necessary to measure the influences of angles of attack against models' static or dynamic loads. In the tests, at the same time that we maintained the excitation frequency at 15 Hertz, we took the angles of attack through increases from 2° to 14°. The results were that excitation amplitudes did not follow changes in the angle of attack and change.

In order to precisely specify the dimensions of the exciter devices used on different aircraft and in test projects, in the tests, measurements were also done of the relationship between the normal direction forces, the M number, and the altitude as imposed on units of surface area. For example, when the M number is 0.8 and the altitude is 10,000 English feet (3048 meters), on unit surface areas (square English feet), it was possible to produce 180 pounds (24.9 Newtons) of between-the-peaks dynamic lift. This value is equal to the force produced by vibration movements when the vibrater vane pitch angle goes up and down 4°.

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